

Energy Saving Load-Shedding Ballast for Fluorescent Lighting Systems

Year 1 Summary Presentation

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Work Funded by
Connecticut Light and Power Company

Ballast Options for Energy Efficiency

(High Frequency Electronic)

Ballast type	System Efficacy		Comments
	T8 LPW	Super T8 LPW	
Instant Start	76	91	Inexpensive
Rapid Start	72	86	Improved lamp life (?)
Programmed Start	75	90	Much improved lamp life (better starting)
Dimming	68	82	Able to dim

Load-shedding Ballast

A new option for efficiency and load management

Key concepts

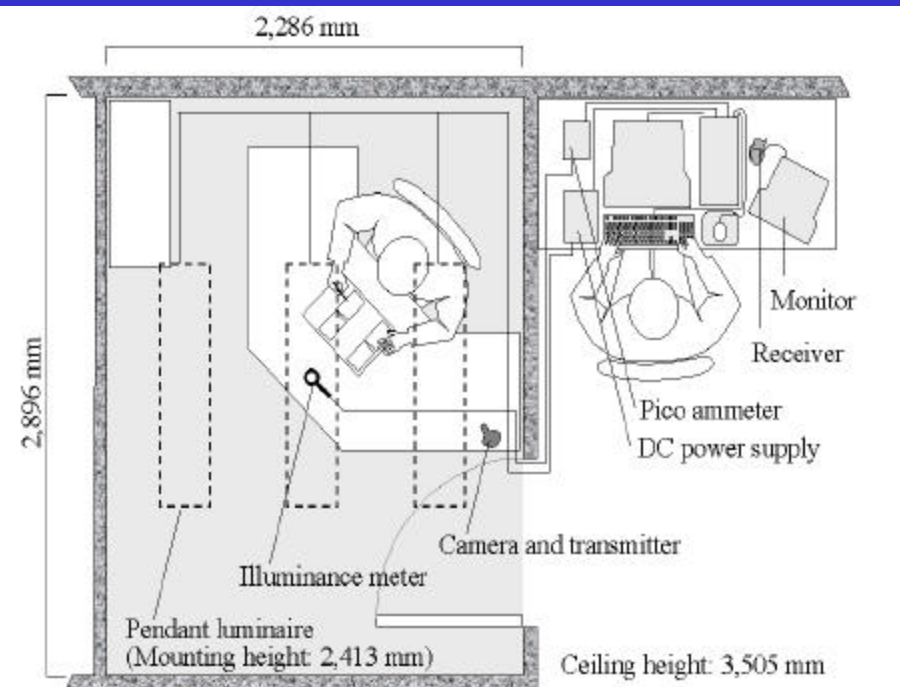
- Enables dimming control for load management with little or no penalties on efficacy and cost
- Limit dimming range
 - Simplifies ballast design (cost saving)
 - Maintains high efficacy (no electrode heating)
- Full dimming is not necessary to get the majority of the benefits from load management
- Start with “Programmed-Start” ballast platform for rapid development (OSI recommendation)

Year 1: Concept/Ballast Development

- Task 1.
 - Investigate occupants' dimming requirements
- Task 2.
 - Investigate the effects of dimming on lamp life
- Task 3.
 - Obtain input from Connecticut market actors
- Task 4.
 - Investigation of possible control system options for load shedding
- Task 5.
 - Development of a prototype energy-saving load-shedding ballast

Task 1. Occupants' Requirements

How low should you go?



Human factors experiments to establish acceptable dimming range.

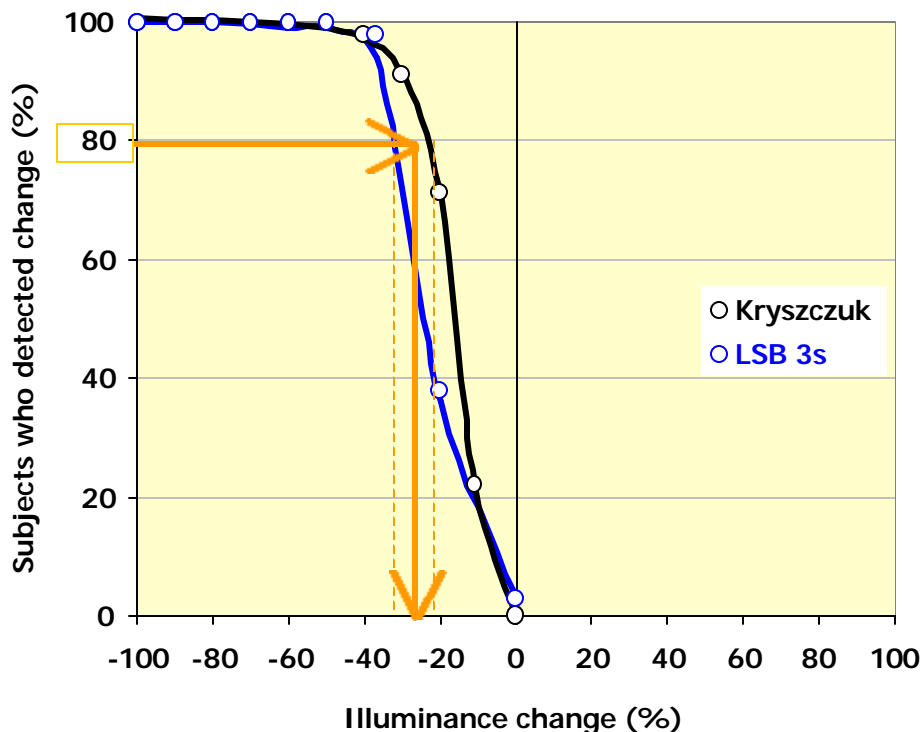
Experimental Design

3 stages of experiments

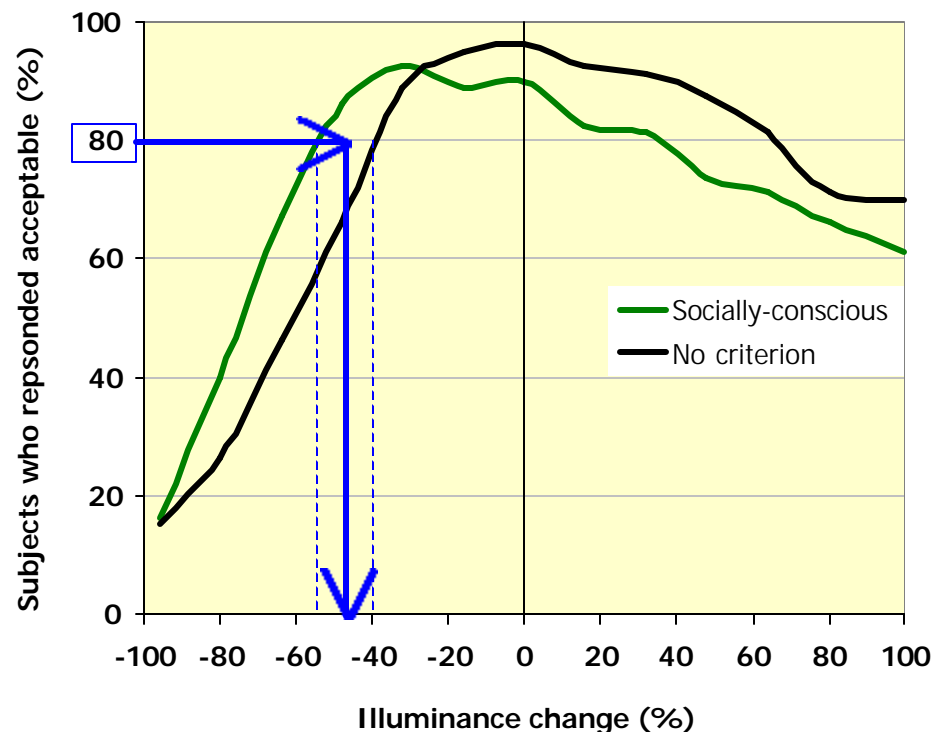
1. Memory of initial illuminance (detectability)
2. Dimming curve study
3. “Bias study”: How motivation and social consciousness affect acceptability of dimming

Results of Human Factors Experiments

Detectability



Acceptability



- Dimming speed and task conditions have little influence on detectability; 80% of the people could detect the change in illuminance after about a 30% or greater reduction from initial illuminance
- The acceptable dimming level can be lower ~ 40% to 55%

Task 2. Lamp-Ballast Technology

How low can you go?

- Literature study with some limited testing
- Investigated how dimming effects lamp life

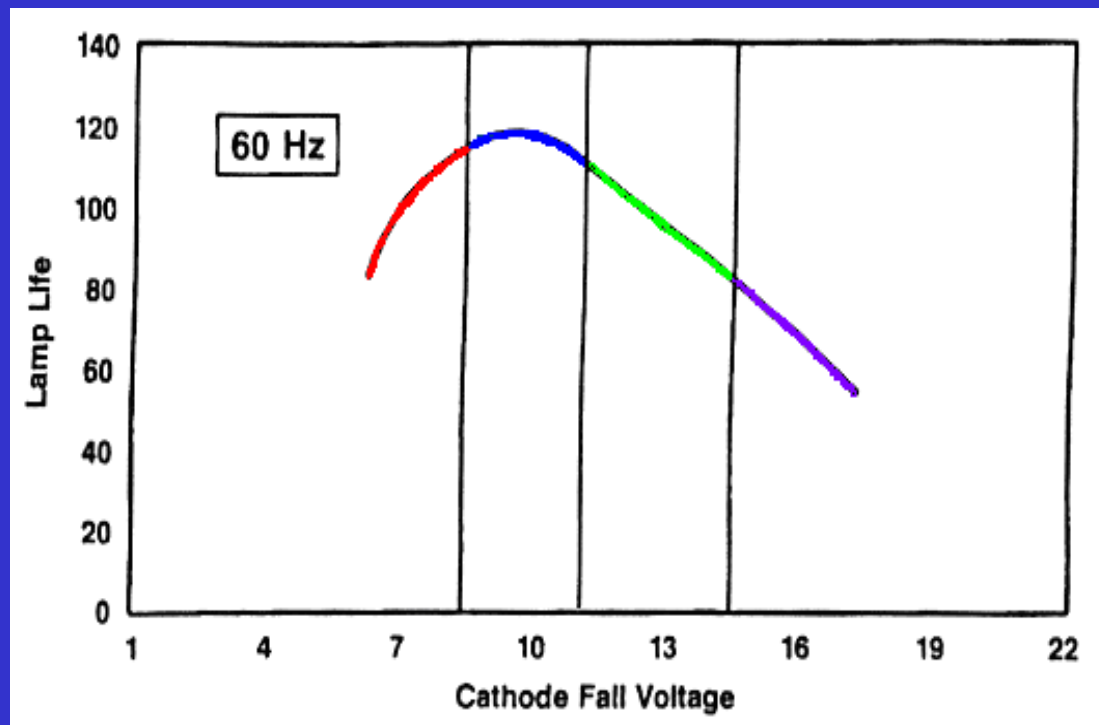
Basic Theory

- Life is determined by life of electrodes
- Maintaining proper electrode temperature is key to long life
 - Too cold -> Sputtering
 - Too hot -> Evaporation
- Electrode Thermal Model
 - Self-heating by lamp current (cathode fall voltage)
 - Supplemental resistive heating provided by ballast circuit (rapid-start type ballasts)
 - All types of heating are not the same; spatial and temporal differences affect lamp operation and lamp life

Task 2 Findings

- Most available data and literature are for LF operation (60 Hz)
- Recent work shows HF operation to be very beneficial to self-heating of electrode
 - Explains observed high performance of IS electronic ballasts
 - Suggest that dimming without supplemental electrode heating is not as damaging for HF operation as once thought

Postulated lamp life (%) vs. cathode fall voltage (V) at 60 Hz (Hammer, 1995).



— Thermal evaporation range

— Addition cathode heat range

— Normal operating range

— High ion bombardment sputtering range

Experimental results



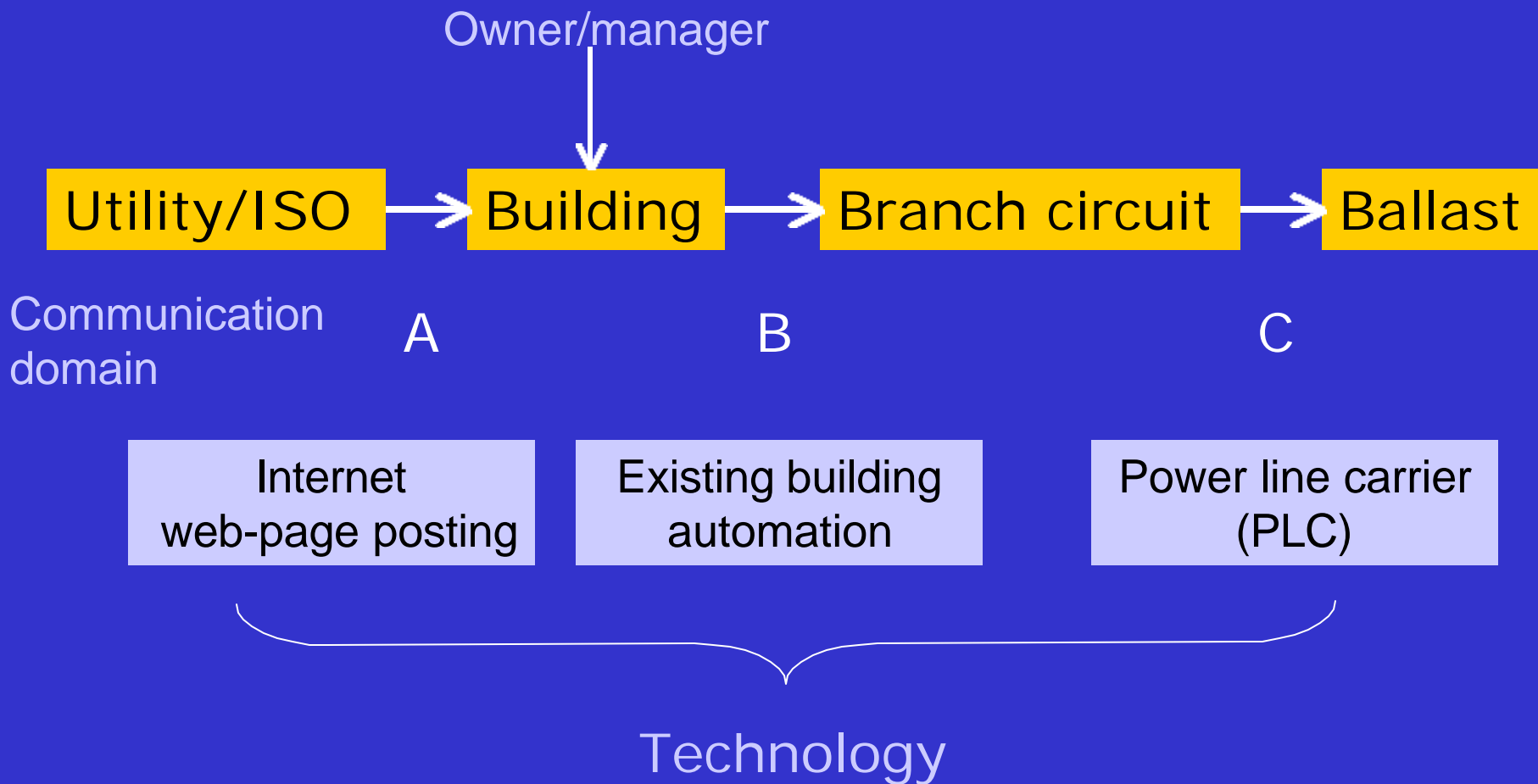
Task 3. Input from Connecticut Market Actors on Load Shedding Concept

- Held roundtable near Hartford, CT May 22, 2002
- Attendees:
 - 5 lighting controls manufacturers.
 - 3 ESCOs
 - 1 large end-user (U-Mass)
 - ISO New England
- No “show stoppers” were identified
- ESCOs not enthralled by idea, highly skeptical and uncertain – need economic assurances
- Cost of technology and third party support are key to its success

Task 4. Control System Options

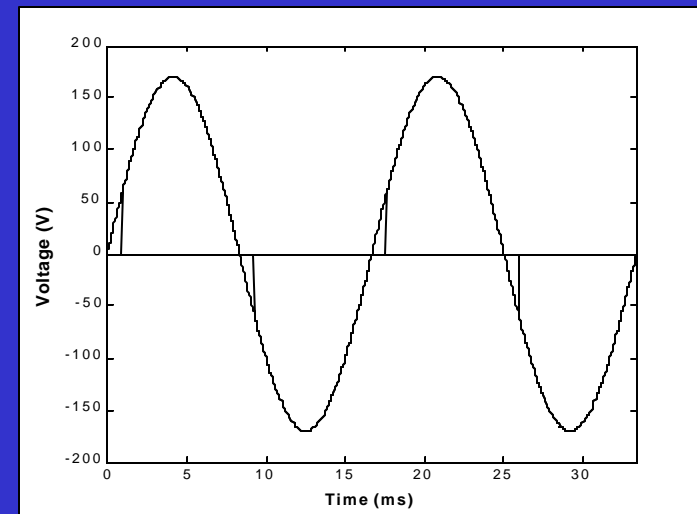
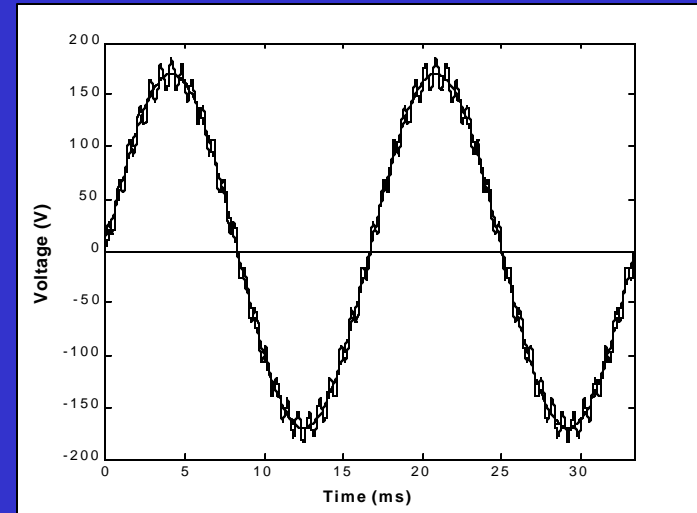
- Purpose
 - Aggregate load and provide dimming control and access
- Requirements
 - One-way communication
 - on/off binary signal
 - Extremely low speed (1 bit per minute)
 - Reliability commensurate with existing controls
 - Does not conflict/interfere with existing systems

3-Domain Architecture

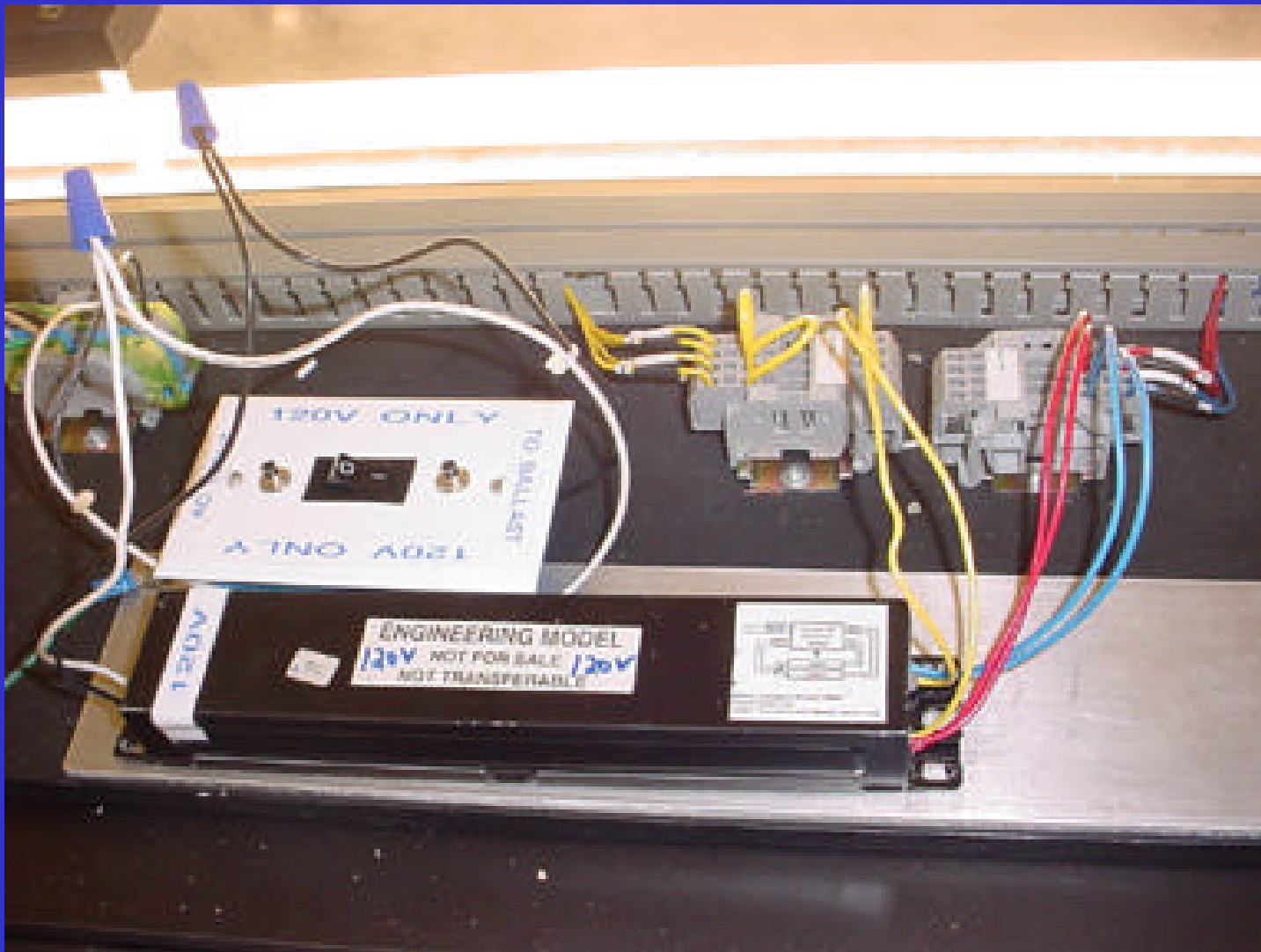


Why PLC?

- Low cost
- No new infrastructure
- Meets speed requirements
- Can be made reliable
 - New modulation techniques
 - Advances in signal processing ability



Task 5. The Load-shedding Ballast Prototype Made by OSRAM-Sylvania



Specifications

- Input voltage: 120 V
- Lamp type: two, 32 watt T8
- Programmed start (heating electrodes during lamp starting sequence)
- Series lamp operation
- One step dimming
 - maximum ramp period: 10 seconds
- No supplemental electrode heating during operation
- Reduced power demand when input voltage drops more than 10% during non-load-shed condition
- Load shedding
 - 60 to 47 watts
 - 100% to 75% light output
- **Cost: less than 1.5 time IS “brick” ballast (<\$15)**

Performance

Full light output, 120 V		
	Ballast #1	Ballast #2
Input current (mA)	549.5	512.7
Input power (W)	65.1	60.7
Power Factor	1.00	1.00
Current THD (%)	2.14	2.73
Lamp Current (mA)	0.213	0.190
Lamp CCF	1.46	1.46
Lamp Frequency (kHz)	45	45

Performance

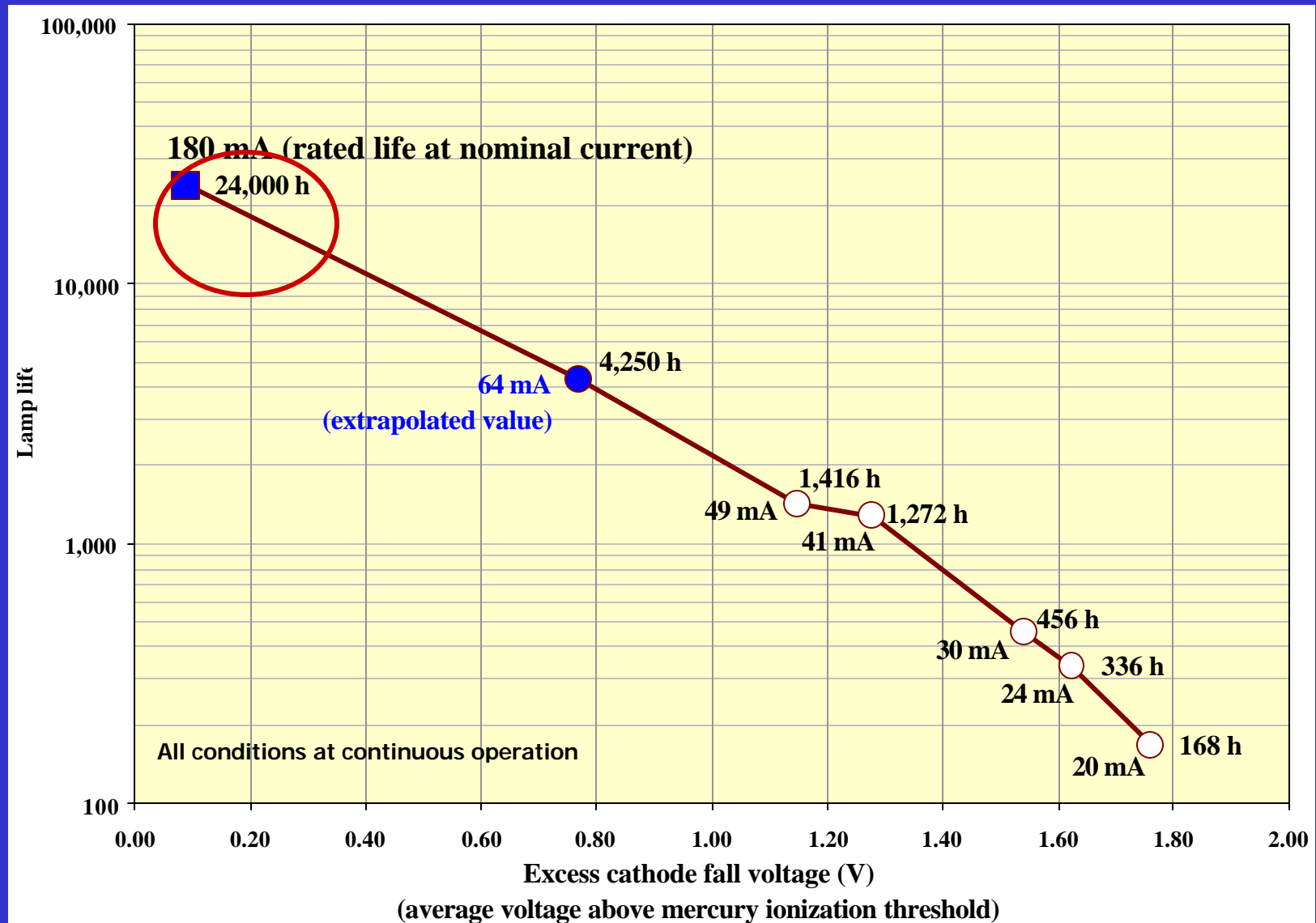
Load shedding, 120 V		
	Ballast #1	Ballast #2
Input current (mA)	412.9	426.1
Input power (W)	49.0	50.8
Power Factor	1.00	1.00
Current THD (%)	1.93	2.16
Lamp Current (mA)	0.143	0.146
Lamp CCF	1.47	1.44
Lamp Frequency (kHz)	55	52
Light output reduction (%)	29	19
Power Reduction (%)	24.8	16.4

Performance

Efficiency Comparison

Ballast type	Ballast Efficiency Factor (BEF)	BEF Standard Deviation	Relative Efficacy	Input Power for Equal Light Output
Load-shedding Prototype	1.49	N/A	0.98	61.2
Instant-start	1.52	0.031	1.00	60.0
Rapid-start	1.45	0.048	0.95	63.2
Conventional Dimming Ballast	1.38	0.049	0.91	65.9

Lamp Life under Load-shed Condition



Performance

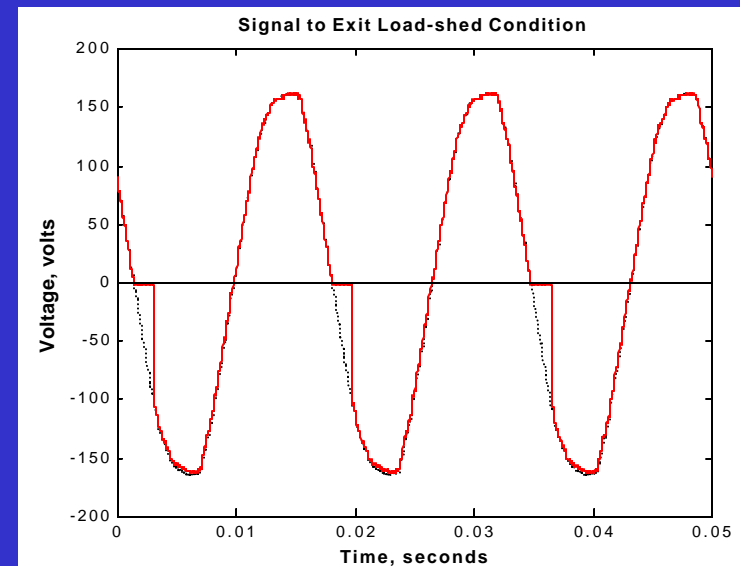
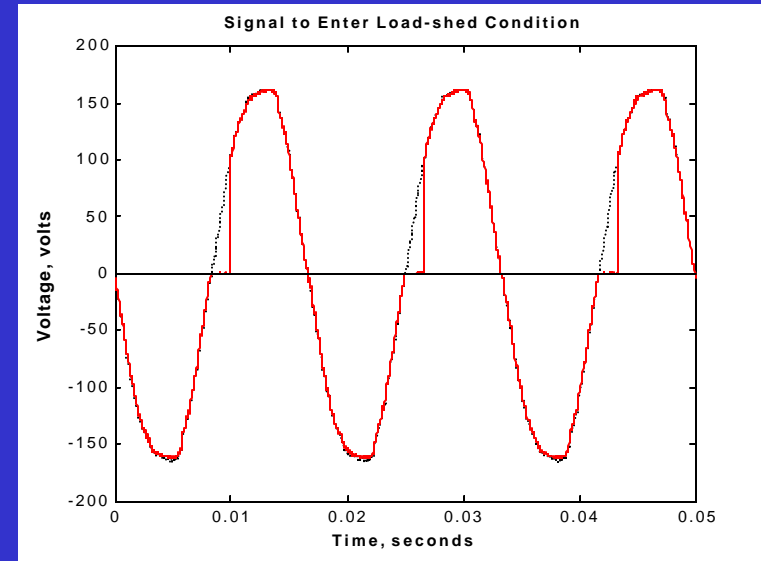
PLC Control

Advantages

- Large signal strength
 - Easy reception
- Low frequency
 - Avoids interference
 - Long range
- Short signaling period (2 seconds)

Disadvantages

- Series connection
 - Difficult installation
 - High current handling
- Significant voltage distortion
 - 14% THD
 - 2% V_{rms} reduction



Conclusions

- Prototypes met all performance metrics (on average) except dimming ramp period
- Efficiency is nearly as high as Instant-start benchmark (98% as efficient)
- Load shed operation is expected to have minimal impact on lamp life
 - Possible to extend load-shedding duration beyond 100 hours/year.
- PLC control works, but needs to be critically evaluated against other PLC options.

LRC Project Team

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Project 3.2

Energy Efficient Load Shedding Technology

- Project Objective
 - To develop a load shedding ballast and retro-fit load shedding device for instant-start T-8 fluorescent lamp systems. Development includes a detailed device specification, manufactured prototypes and laboratory testing of prototypes.
- Expected Applications
 - All commercial and industrial general lighting applications that use linear, T-8 lamps.
- Market Connection Strategy
 - Holding roundtable event to gain input and to publicize efforts
 - Working with technical group representing lamp and ballast manufacturers
 - Will seek ballast manufacturing partner



Project 3.2

Energy Efficient Load Shedding Technology

- Can instant-start fluorescent systems be dimmed?
 - Preliminary data suggests yes, but to a limited extent
 - Lamp life trade-off, must limit dimming period
 - Suitable for load shedding applications
- Life tests
 - Determine suitable dim levels and allowable dimming periods
 - Needed for dimming specification

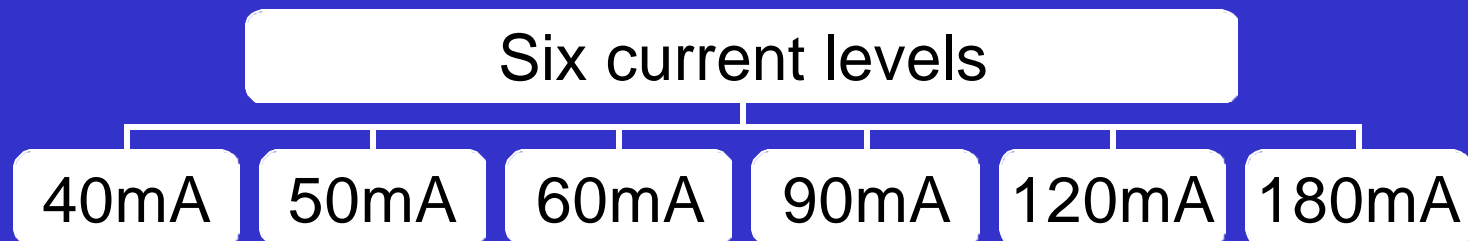


Life testing racks

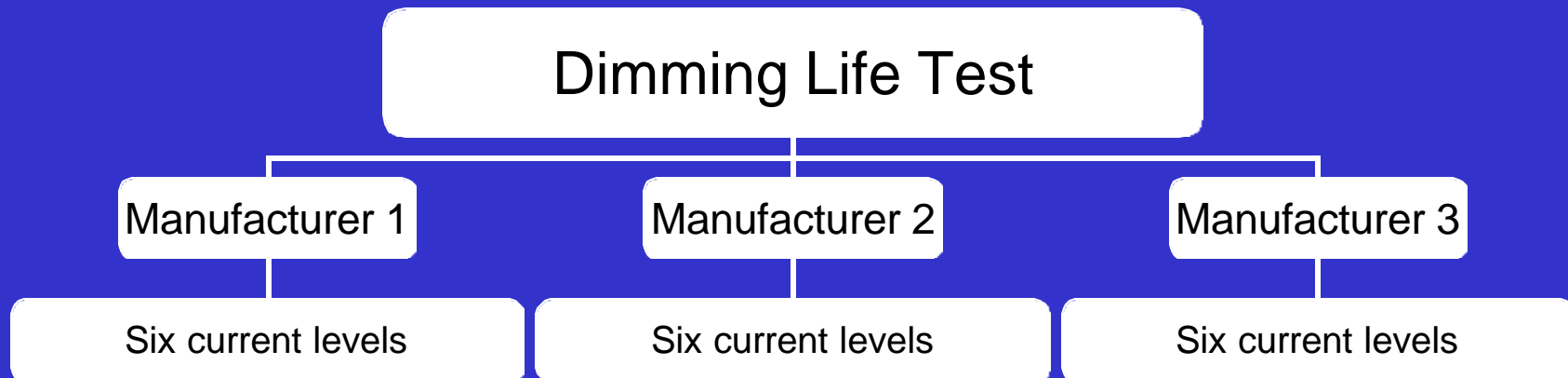
Life test

Lamp life for continuous operation at dimmed light levels.

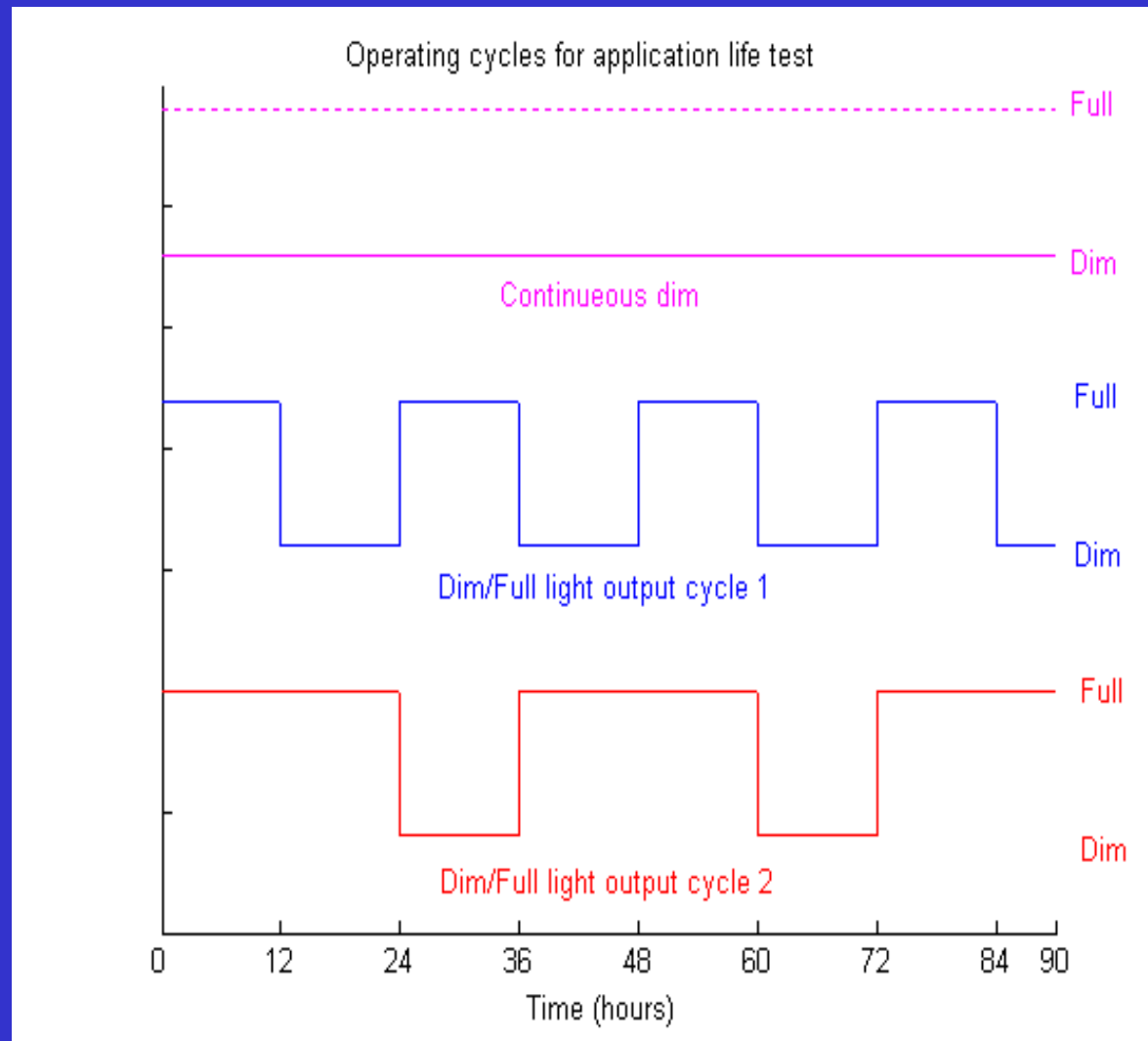
- Investigate lamp life at different current levels
- Investigate relationship between lamp life and cathode fall voltages



Check it with lamps from three different manufacturers



Life test



Continuous
dim

50% duty cycle

4 hours full / 4 hours dim

33% duty cycle

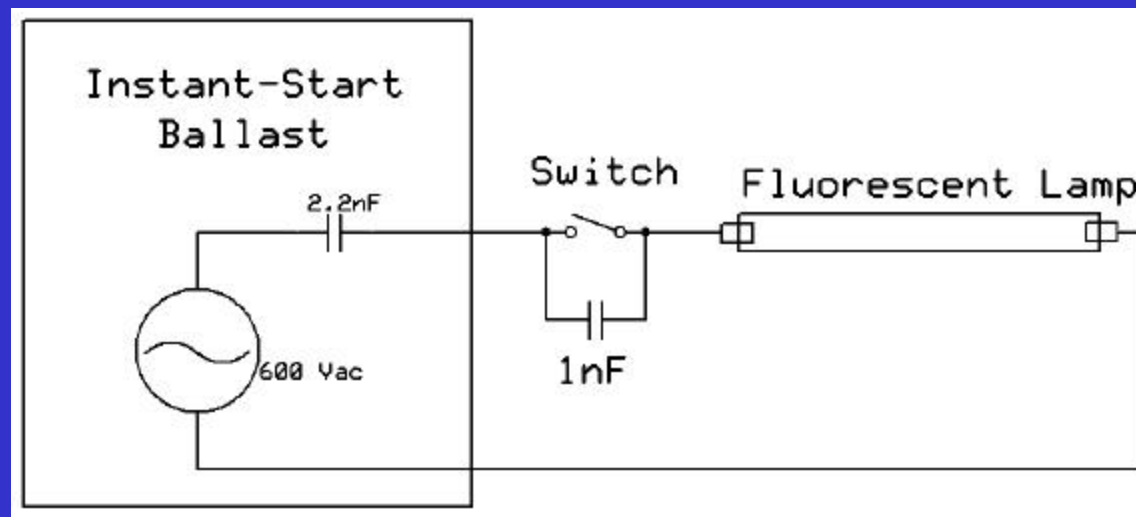
8 hours full / 4 hours dim

Project 3.2

Energy Efficient Load Shedding Technology

Develop extremely low cost method of dimming instant-start operated lamps

- Laboratory trials demonstrate that adding reactive current limiting elements between lamp and ballast are effective and potentially inexpensive
- Must develop automatic method of dimming that can be activated by remote signaling



Project 3.2

Energy Efficient Load Shedding Technology

California Events March 5th and 6th

- Customer Focus Group
- Roundtable (Utilities, Project sponsors, Control manufacturers, Lighting researchers)